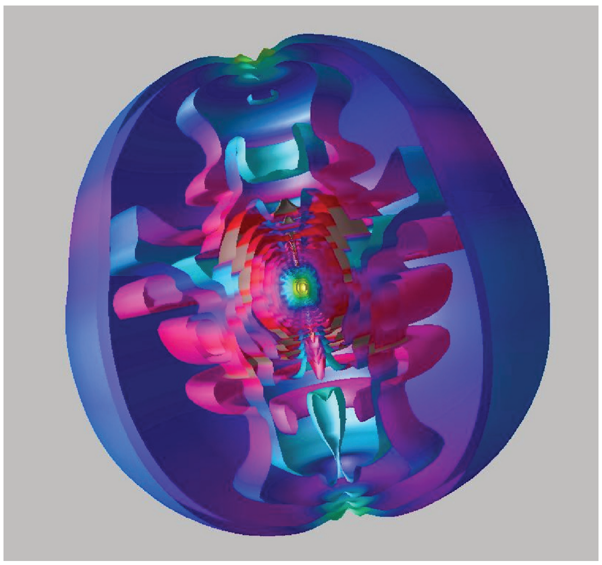
Groundbreaking Simulations of Core-Collapse Supernovae

Researchers discovering clues behind mysterious natural phenomena



A rendering of the exploding supernova core, generated in the radiation/hydrodynamic simulations of A. Burrows and collaborators. The newly born neutron star is at the center, surrounded by a mantle of outward-flowing material.

Core-collapse supernovae play important roles in several aspects of the evolution and composition of galaxies like our own. These spectacular events mark the violent deaths of stars larger than about 8 solar masses (eight times the mass of our Sun) and are the most common type of exploding star in the universe, ten times more common than their thermonuclear counterpart, the Type Ia supernovae, created when a white dwarf consisting of carbon and oxygen detonates. Besides littering the interstellar medium with chemical elements, core-collapse supernovae are also responsible for producing black holes, neutron stars, pulsars, and possibly gamma-ray bursts. The energy generated by these explosions is a major force behind star formation and galactic evolution. When they explode, core-collapse supernovae can be brighter than whole galaxies and their incredible luminosity is being investigated for use as standard candles against which to measure the size and shape of the universe.

Understanding core-collapse supernova explosions is "one of the most fundamental unsolved problems in astrophysics," says Dr. Adam Burrows of the University of Arizona, adding that our lack of understanding is largely the result of a lack of computer muscle. Until recently computers simply were not able to handle the calculations necessary for an accurate simulation. Now, however, they are becoming capable of performing the complex, multidimensional simulations needed to decipher the mechanisms responsible for these powerful explosions. With their Vulcan 2D code, Dr. Burrows and his team are conducting "first-of-their-kind" simulations that incorporate the latest computational techniques.

Burrows says he chose the National Center for Computational Sciences (NCCS) because of its immense resources. The mystery of core-collapse supernovae is at the "cutting edge of numerical arts," says Burrows, adding that to run useful simulations his team needs the fastest machines at its disposal. Even with Burrows's efficient Vulcan 2D code and the NCCS's raw computing power, one simulation can take anywhere from 2 to 4 months.

While Burrows admits that Vulcan 2D isn't as accurate as necessary, he argues that the code is among the most sophisticated employed in the quest to solve this important problem. "It allows you to follow the inner regions in ways other codes can't," says Burrows. This is an extremely important advancement because Burrows believes that physics and dynamics in the core might be vitally important to the explosion mechanism. Burrows also cites Vulcan 2D's "gravity solver"—which calculates the gravitational field in the tumultuous interior of the star—as another of Vulcan 2D's advances.

So far, says Burrows, he and his team have run about 25 to 30 simulations over the last 2 years. "We learn something new from most of them," he says. While historically many in the field have believed the sole explosion mechanism to be neutrino heating, Burrows isn't convinced. His recent simulations suggest that oscillations in the core might play a role as well. His simulations suggest that the anisotropic, or aspherical, core might push against the surrounding gas, producing sound waves (much like a stereo speaker). These sound waves could eventually become shock waves, which Burrows believes might work with the neutrinos to produce an explosion. However, he admits that no one really knows, predicting that it could take up to 10 years for the scientific community to fully understand the phenomena.

Assuming, that is, that computer technology continues to advance at its current rate. While recent advances in computing power have made more accurate simulations possible, the technology is still insufficient to run adequately sophisticated simulations. Burrows and his team are currently capable of running hydrodynamics simulations in three dimensions, but running both hydrodynamics and radiative transfer in 3-D simultaneously is far beyond current computing capabilities. "We need speed . . . we need memory," says Burrows, who estimates that computers need to be 1,000 times faster to correctly simulate the coupled phenomena in 3-D. Furthermore, these enormously complicated simulations produce huge datasets, which in turn require large computers and large teams to analyze. "Computers just aren't fast enough to do what we need to do," says Burrows, adding that his team is making "slow, incremental progress."

The simulations are an ongoing process. After each successful run, Burrows and his team alter the parameters to determine the outcome of many of the possible scenarios. They expect to complete more than their previous 25 to 30 simulations over the next 3 years, the expected duration of the project. With each new run comes new data, bringing science one step closer to understanding our origins and the behavior and dynamics of our universe.

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